THE EFFECT OF SOME TRIVALENT AND TETRAVALENT KATIONS ON PERMEABILITY

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(WITH SEVEN FIGURES)

It has been shown[1] that there is a remarkable difference between monovalent and bivalent kations in their effects on permeability. None of the monovalent kations investigated (except H) are able to decrease permeability, while all of the bivalent kations investigated are able to do so to a marked degree. In view of this it becomes important to make similar investigations on the effects of trivalent and tetravalent kations.

It is desirable in these investigations to use salts which give neutral solutions, since, as has been previously shown,[2] both acid and alkali affect permeability. For this reason salts of lanthanum are especially useful; nitrates of yttrium and cerium were also employed, as they likewise give neutral solutions when used as here described. Some experiments were made with ferric sulphate and with aluminum salts, but these substances have the disadvantage of giving acid solutions.

The salts used were in all cases the purest obtainable and the distilled water was prepared with especial care.

A solution of $La_2(NO_3)_6 \cdot 12\ H_2O$ of the conductivity of sea water was made by dissolving 31.5 gm. in 297 cc. of distilled water. The concentration was about 0.126 M. A lot of tissue which had a resistance in sea water of 1350 ohms was transferred to the lanthanum solution. The resistance rose rapidly to a maximum of 2350 ohms after which it gradually fell. In a second experiment the resistance at the start was 880 ohms and the maximum resistance 1490 ohms. The results are shown in table I and fig. 1.

[1] Osterhout, W. J. V., On the decrease of permeability due to certain bivalent kations. Bot. Gaz. 59:315–330. *figs. 11.* 1915.

[2] ———, Extreme alterations of permeability without injury. Bot. Gaz. 59:242–253. *figs. 4.* 1915.

At the beginning of the first experiment the resistance was 1350 ohms; from this we must substract the resistance of the apparatus (240 ohms) to get the resistance of the tissue itself or the net resistance. This was 1350−240=1110 ohms, and the net conductance 1÷1110=0.000901 mho. The net resistance at the maximum was 2350−240=2110 ohms, and the net conductance was 1÷2110=0.000474 mho. We may regard the permeability as equal to the conductivity, or for convenience we may, in such a case as this, regard it as equal to the conductance. The loss in permeability therefore was 0.000901−0.000474=0.000427 mho or 47.4 per cent.

TABLE I

Electrical resistance of *Laminaria saccharina;* two experiments

Time in hours	In $La_2(NO_3)_6$ 0.126 M	In $CaCl_2$ 0.278 M	In sea water
0	1350	1300	1400
0.17	2080	1640	....
0.33	2160	1730	....
1	2350	1730	....
1.83	2315	1640	....
3.33	2030	1490	1400
10	1340	600	1370
18	880	400	1350
0	880	....	890
0.5	1490	....	....
1	1360	....	....
2	1320	....	....
5.5	740	....	....
9.5	525	....	890

All readings were taken at 18° C.

The net resistance at the beginning of the second experiment was 880−250=630 ohms, and the net conductance was 1÷630=0.00159 mho. The net resistance at the maximum was 1490−250=1240 ohms, and the net conductance was 1÷1240=0.00081 mho. The loss in permeability therefore was 0.00159−0.00081=0.00078 mho or 49.1 per cent. Similar results were obtained with La_2Cl_6. It will be seen that the rise in resistance is much greater in $La_2(NO)_6$ and La_2Cl_6 than in $CaCl_2$.

It has been pointed out[1] that the severest test of the ability of a salt to decrease permeability is to add the salt in solid form to the

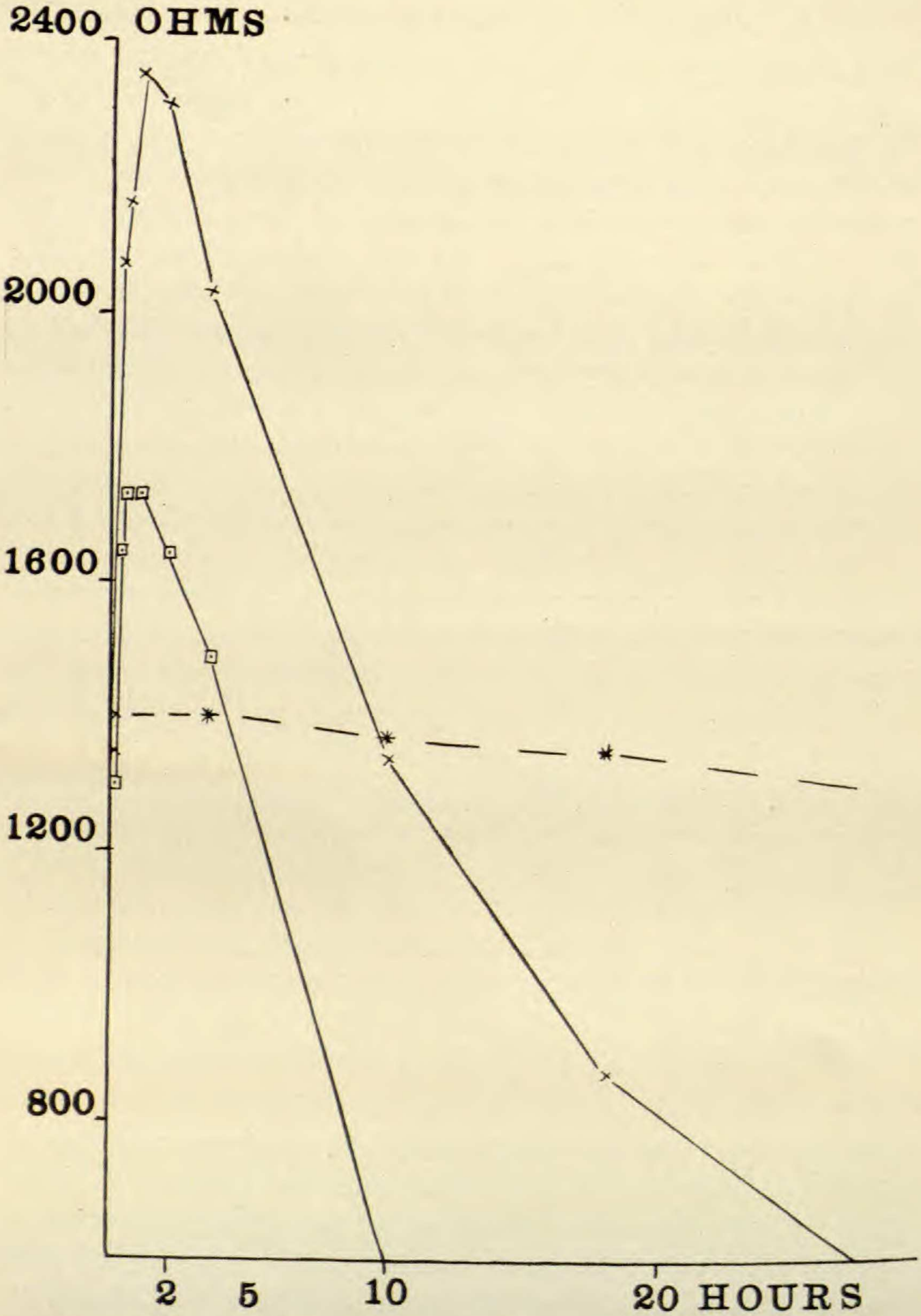

FIG. 1.—Curves of electrical resistance of *Laminaria saccharina* in $La_2(NO_3)_6$ 0.126 M (line with crosses), in $CaCl_2$ 0.278 M (line with squares), and in sea water (dotted line).

sea water. The results of such an experiment are shown in table II and fig. 2. To 275 cc. of sea water 5 gm. $La_2(NO_3)_6 \cdot 12\ H_2O$ were

TABLE II

ELECTRICAL RESISTANCE OF *Laminaria saccharina*

Time in hours	In sea water 275 cc. + $La_2(NO_3)_6 \cdot 12\ H_2O$ 5 gm. (= 0.021 M)	In sea water
0	1090	1080
0.08	1210	1080
0.75	1210	....
1.25	1210	....
2	1190	....
17	980	1030
22.5	935	1000

All readings were taken at 18° C.

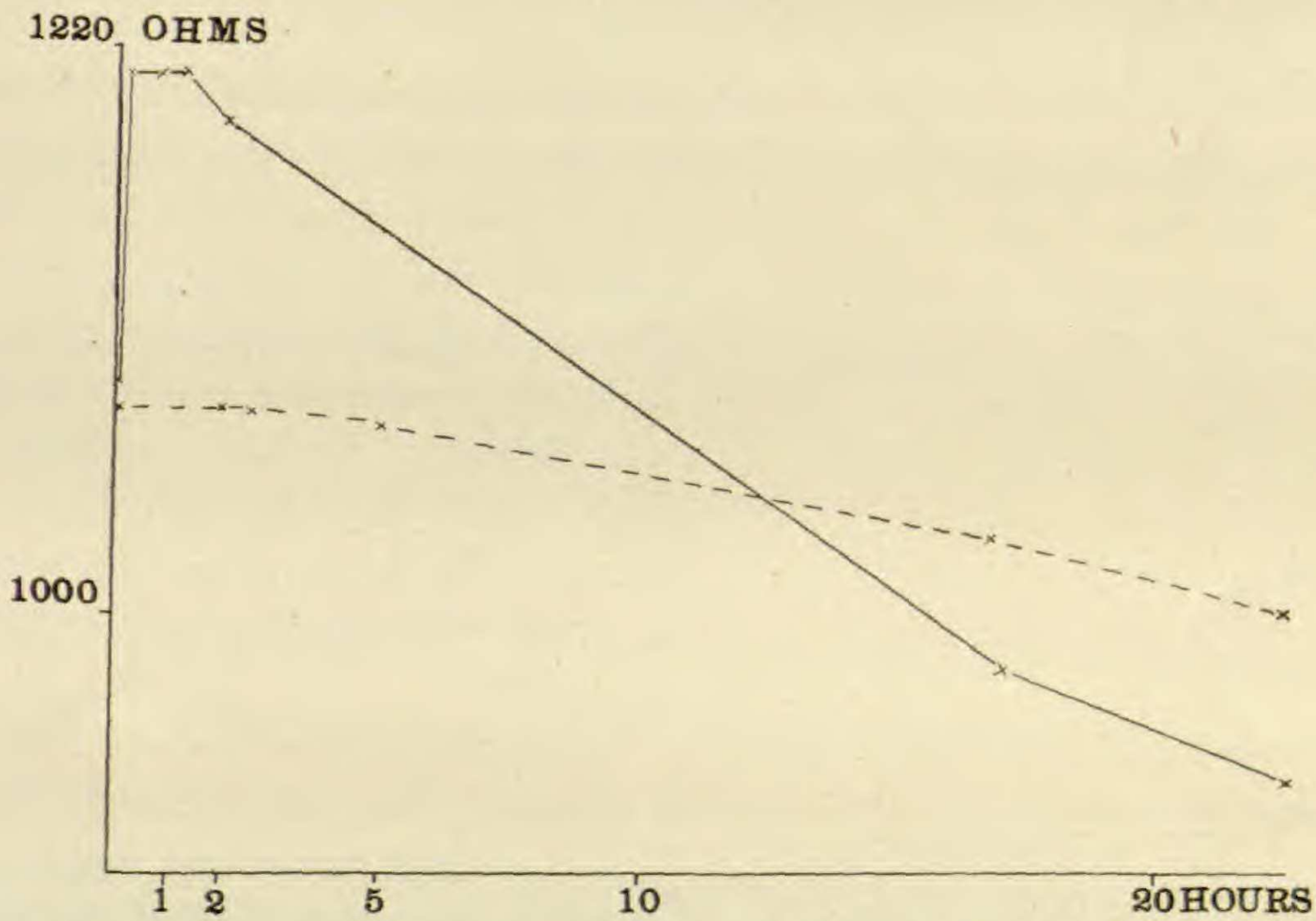

FIG. 2.—Curve of electrical resistance of *Laminaria saccharina* in sea water 275 cc. + $La_2(NO_3)_6 \cdot 12\ H_2O$ 5 gm. (= 0.021 M) (unbroken line), and of a control in sea water (dotted line).

added, making the concentration 0.021 M. In this the resistance of a lot of tissue rose rapidly from 1090 to 1210 ohms, where it remained stationary for a time and then began to fall. In the course of 17 hours it fell to 980 ohms, while that of the control fell 50 ohms in the same time. Dead tissue gave no rise in resistance.

TABLE III

ELECTRICAL RESISTANCE OF *Laminaria saccharina*

Time in hours	In sea water 300 cc.+ $Ce_2(NO_3)_6 \cdot 12\ H_2O$ 0.8 gm.=(0.003 M)	In sea water
0	840	810
0.16	860	....
0.5	970	....
1.5	990	....
4	860	800
19	420	770

All readings were taken at 18° C.

The addition of the salt in solid form increases the conductivity of the solution. In order to produce a rise in resistance when added in this way, the action of the salt must be great enough to overcome the fall in the resistance of the solution which is contained in the apparatus and in the intercellular substance[3] of the tissue.

As has been pointed out,[1] such experiments furnish conclusive proof that the current passes through the protoplasm as well as through the intercellular substance.

In a previous paper the results of exposing the tissue alternately to sea water and to sea water+ $La_2(NO_3)_6$ were described in detail. The experiment shows that repeated exposure to sea water+ $La_2(NO_3)_6$ produces no injury.[4]

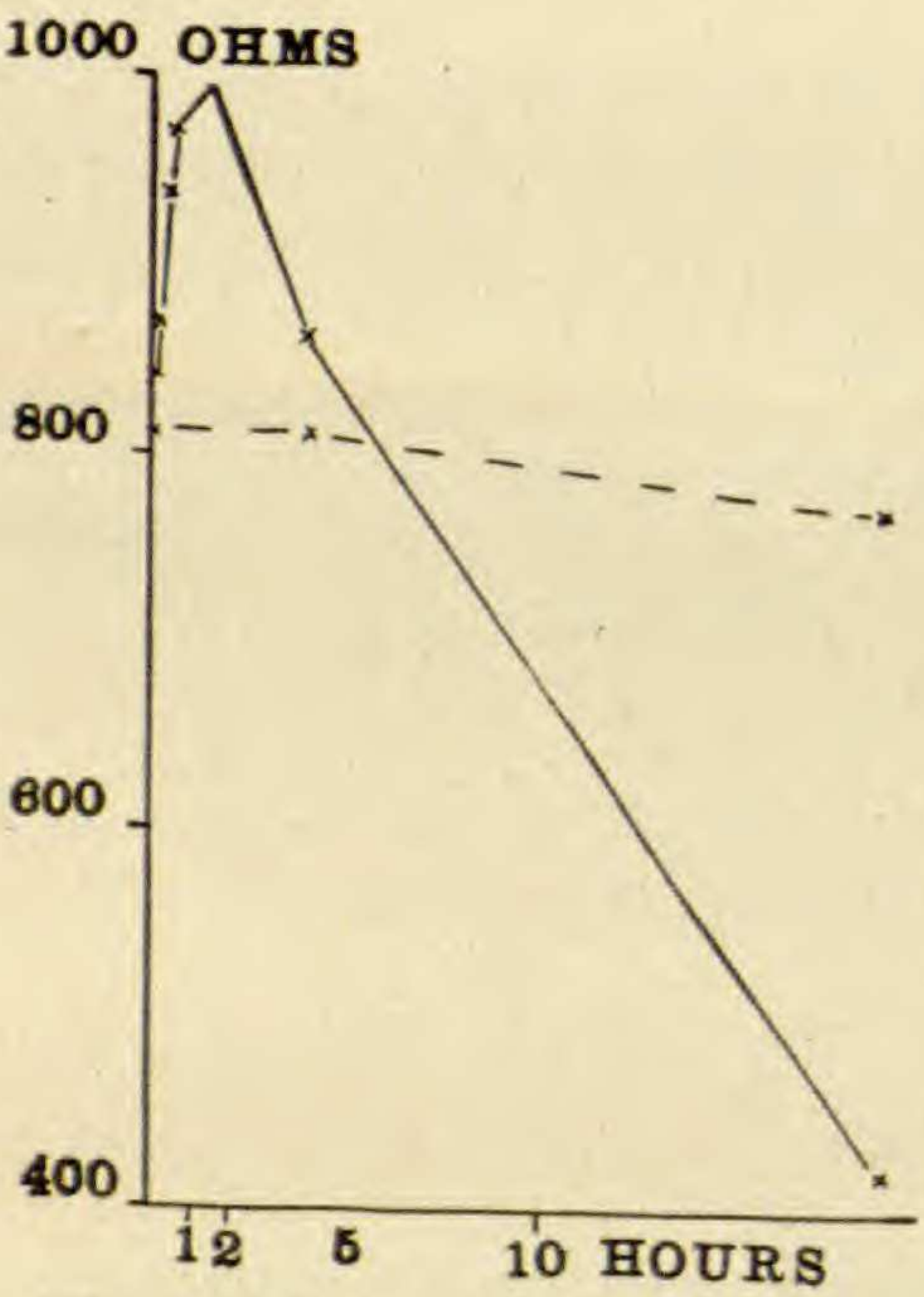

FIG. 3.—Curve of electrical resistance of *Laminaria saccharina* in sea water+ $Ce_2(NO_3)_6 \cdot 12\ H_2O$ 0.8 gm. (=0.003 M) (unbroken line), and of a control in sea water (dotted line).

[3] The frond may be regarded as a mass of intercellular substance in which numerous masses of protoplasm (the cells) are imbedded.

[4] Science **36**:350. 1912.

A lot of tissue which had in sea water a resistance of 840 ohms was placed in sea water to which $Ce_2(NO_3)_6 \cdot 12\ H_2O$ had been added (0.8 gm. to 300 cc. of sea water, making the concentration 0.003 M). In the course of 30 minutes the resistance rose to 970 ohms; during the next hour it continued to rise, reaching a maximum of 990 ohms, after which it slowly fell. The results are given in table III and fig. 3.

TABLE IV

ELECTRICAL RESISTANCE OF *Laminaria saccharina*

Time in hours	In sea water 300 cc. + $Y(NO_3)_3 \cdot 6\ H_2O$ 0.8 gm. (=0.007 M)	In sea water
0	740	770
0.5	900	....
1.25	940	....
2	970	....
5	900	....
20.5	630	735

All readings were taken at 18° C.

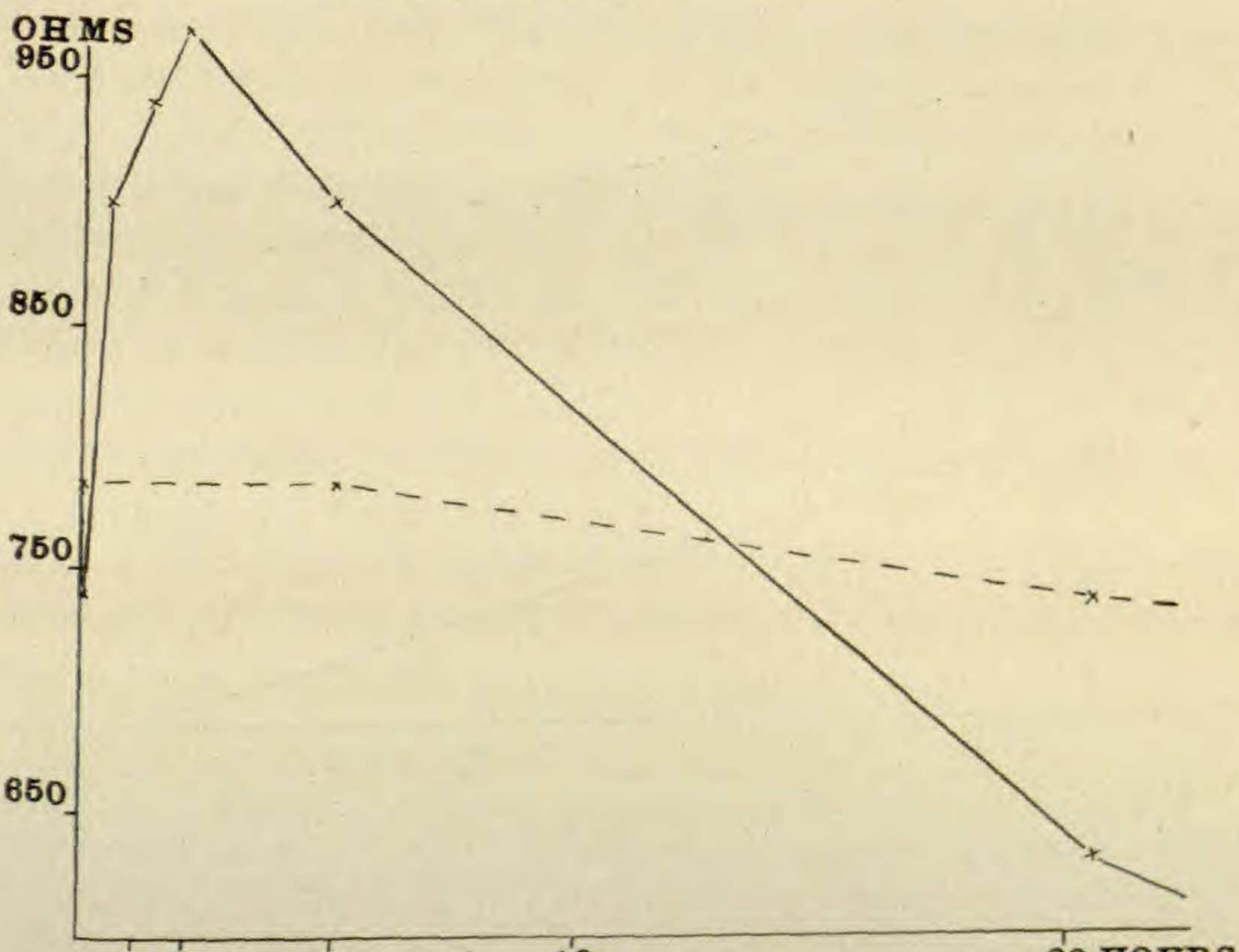

FIG. 4.—Curve of electrical resistance of *Laminaria saccharina* in sea water 300 cc. $+Y(NO_3)_3 \cdot 12\ H_2O$ 0.8 gm.=(0.007 M) (unbroken line), and of a control in sea water (dotted line).

A similar experiment was performed by adding 0.8 gm. $Y(NO_3)_3 \cdot 6H_2O$ to 300 cc. of sea water (=0.007 M) and placing a lot

TABLE V

ELECTRICAL RESISTANCE OF *Laminaria saccharina*

Time in hours	In sea water 1000 cc. + $Fe_2(SO_4)_3$ 1 gm. (=0.0025 M)	In sea water
0	750	730
0.5	810	....
1.5	600	....
17	500	670

All readings were taken at 18° C.

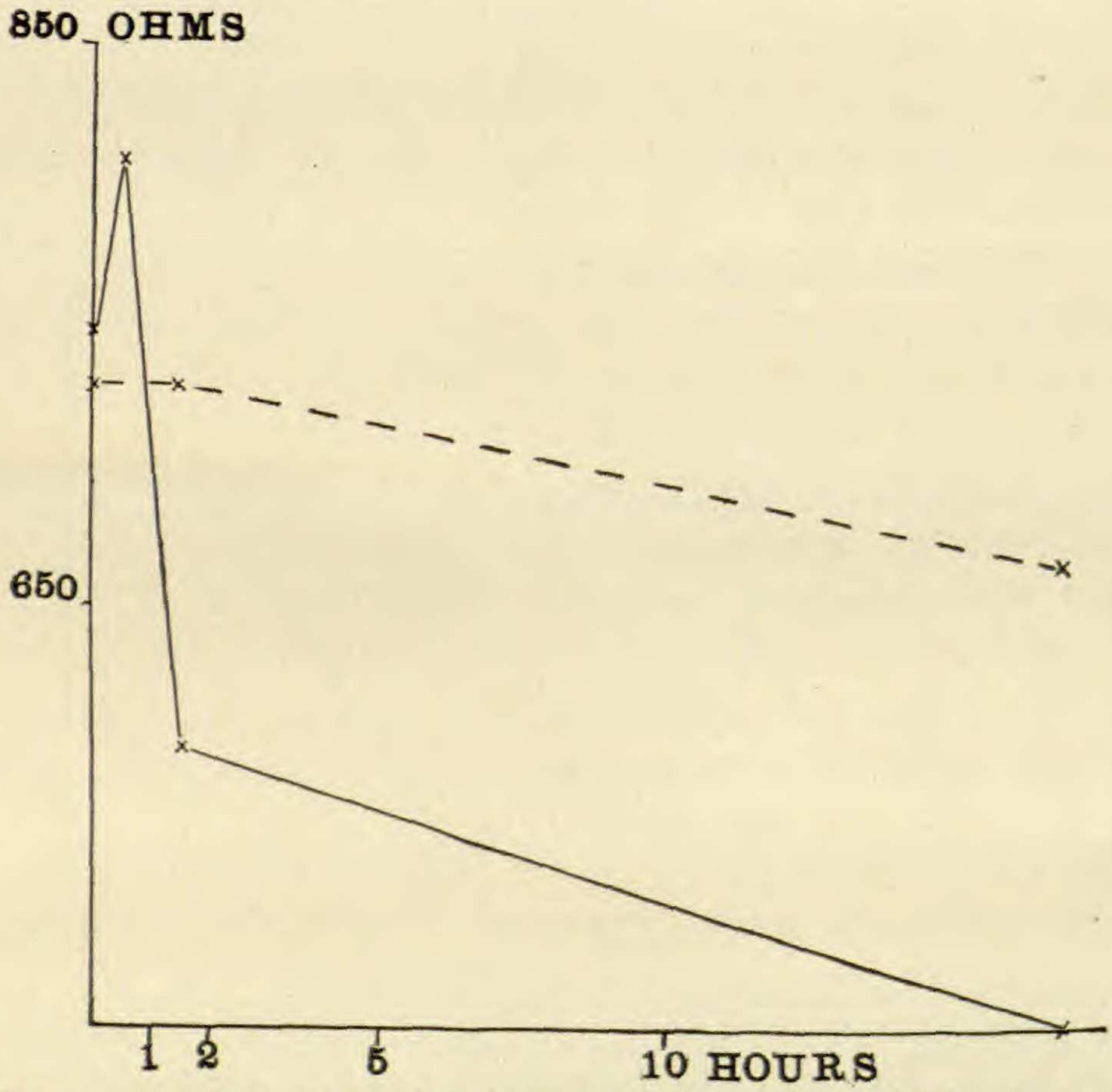

FIG. 5.—Curve of electrical resistance of *Laminaria saccharina* in sea water 1000 cc. + $Fe_2(SO_4)_3$ (=0.0025 M) (unbroken line), and of a control in sea water (dotted line).

of tissue in this mixture.[5] The tissue had in sea water a resistance of 740 ohms; after being transferred to sea water + $Y(NO_3)_3$ the

[5] It should be noted that if the dissociation were equal, a molecule of $Y_3(NO_3)_3$ would yield only half as many kations as a molecule of $La_2(NO_3)_6$ or of $Ce_2(NO_3)_6$.

resistance rose in 30 minutes to 900 ohms, and in the course of 2 hours reached 970 ohms; it then began to fall, and at the end of

TABLE VI

ELECTRICAL RESISTANCE OF *Laminaria saccharina*

Time in hours	In sea water 1000 cc. + $Al_2(SO_4)_3$ 18 H_2O 6.7 gm.	In sea water
0	800	840
0.5	1100	....
0.75	1000	....
1.25	950	....
6.25	370	800

20.5 hours it was 630 ohms. The results are shown in table IV and fig. 4 (p. 469).

Another lot of tissue which had in sea water a resistance of 750 ohms was transferred to sea water 1000 cc. + $Fe_2(SO_4)_3$ 1 gm. (=0.0025 M). The resistance rose in the course of 30 minutes to 810 ohms; at the end of 1.5 hours it had fallen to 600 ohms, and it continued to fall rapidly after this. The solution was acid to litmus, but the degree of acidity was not sufficient to account for the whole of the effect. The results are shown in table V and fig. 5.

Experiments were made with several salts of aluminum, including aluminum chloride, aluminum sulphate, ordinary alum, and chrome alum, which were added in solid form to sea water. All of them gave similar results. The solutions were acid, but the acidity was not great enough to account for the whole of the effect. The action of these salts is illustrated by table VI and fig. 6, which show the results obtained by adding 6.7 gm. $Al_2(SO_4)_3 \cdot 18\ H_2O$ to

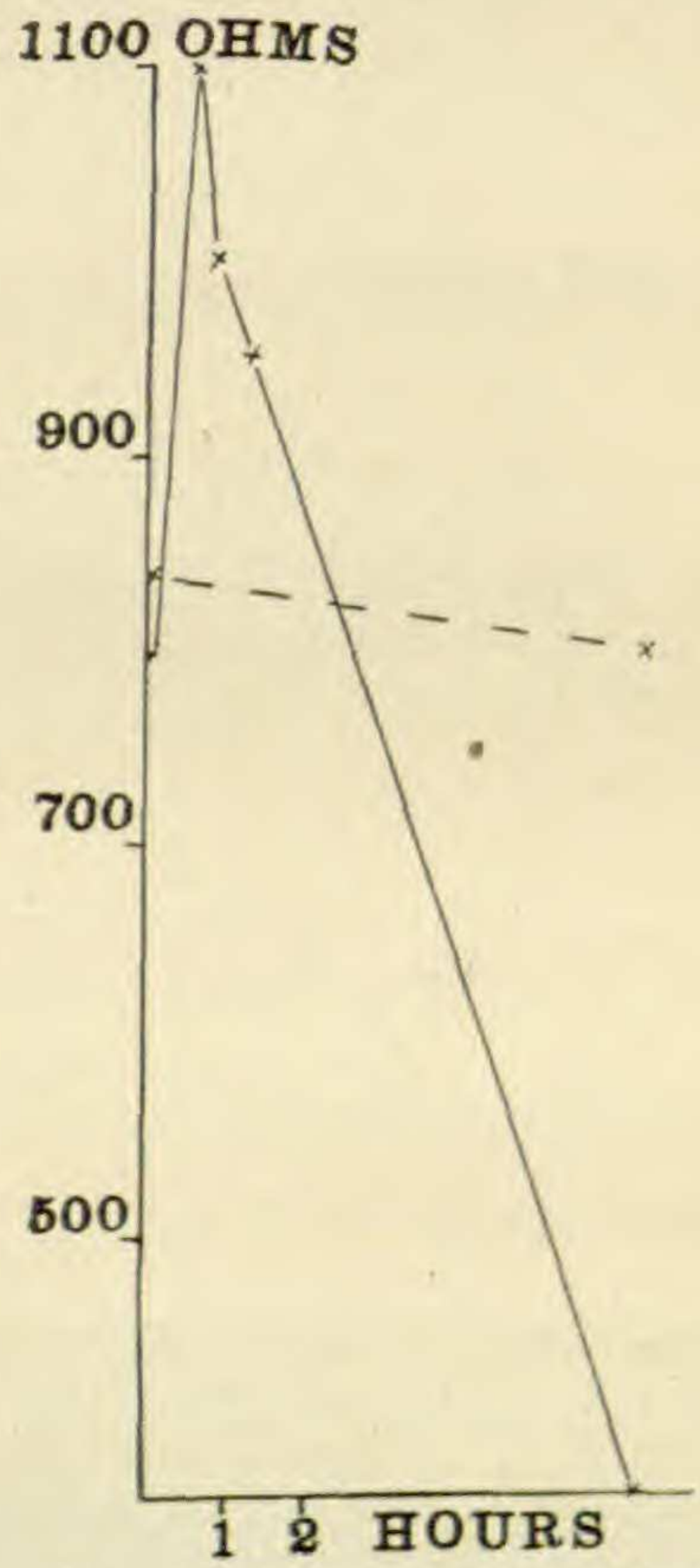

FIG. 6.—Curves of electrical resistance of *Laminaria saccharina* in sea water 1000 cc. + $Al_2(SO_4)_3 \cdot 18\ H_2O$ 6.7 gm. (=0.01 M) (unbroken line), and of a control in sea water (dotted line).

1000 cc. sea water (=0.01 M). It is evident that aluminum salts are very toxic.

As the result of plasmolytic investigations, FLURI[6] came to the conclusion that salts of aluminum (also of lanthanum and of

TABLE VII

ELECTRICAL RESISTANCE OF *Laminaria saccharina*

Time in hours	In sea water 300 cc.+ Th $(NO_3)_4$ 0.4 H_2O 1 gm. (=0.006 M)	In sea water
0	690	720
0.5	750	...
1	760	...
2.5	680	...
5	630	720
7.5	600	...
29	540	660
40	510	640

All readings were taken at 18° C.

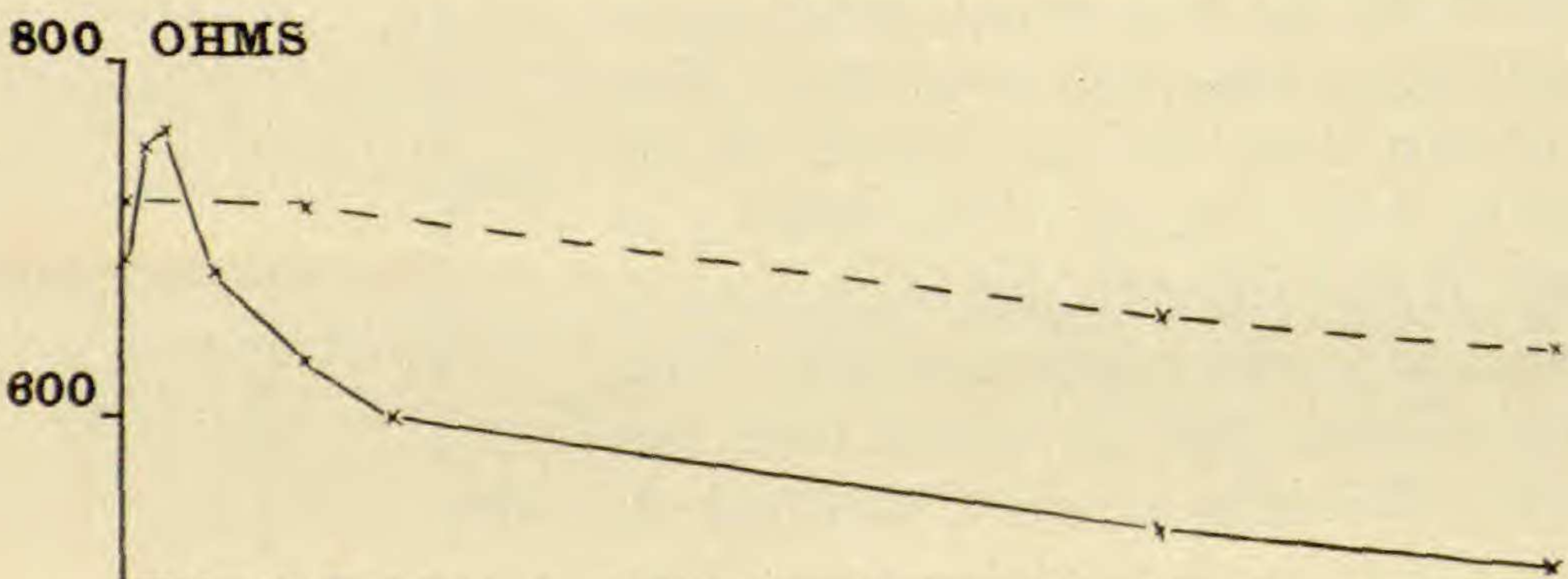

FIG. 7.—Curve of electrical resistance of *Laminaria saccharina* in sea water 300 cc. +Th $(NO_3)_4 \cdot 4\ H_2O$ 1 gm. (=0.006 M) (unbroken line), and of a control in sea water (dotted line).

yttrium) increase protoplasmic permeability. SZÜCS[7] made experiments on the taking up of dyes by the cell and concluded that salts of aluminum decreased the permeability. The experiments described show that both effects are produced. Which effect predominates depends both on the concentration of the salt (as is shown by experiments not mentioned here) and on the length of exposure to its action.

[6] Flora **99**:81. 1908.

[7] Sitzungsber. Wiener Akad. **119**: 1910.

In order to observe the effect of a tetravalent kation, 1 gm. $Th(NO_3)_4 \cdot 4\ H_2O$ was added to 300 cc. sea water, making the concentration 0.006 M. Tissue which had in sea water a resistance of 690 ohms was placed in this solution; the resistance rose in the course of half an hour to 750 ohms; at the end of one hour it was 760 ohms; after this it fell slowly, and at the end of 40 hours was 510 ohms. The results are shown in table VII and fig. 7.

Summary

All of the trivalent kations investigated (La, Ce, Y, Fe, Al) and the tetravalent kation Th are able to decrease permeability to a marked degree.

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